Measurements and Processes:

What do we need to observe, and how accurately do we need to measure it?

(It's an OSSE, Jim, but not as we know it…)

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Context

- We are considering measurement strategies, and discussing poorly known cloud and aerosol processes
- Models are used as a laboratory to test our assumptions
- Questions:
  - How do we know whether an observing system has made a measurement with sufficient accuracy, resolution, or frequency?
  - How do we most effectively use models to test future observing systems?
  - How can we assess the uncertainty inherent in the models themselves?

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Quantifying Observational Requirements
Observing System Simulation Experiments

- Traditionally: evaluation of potential impact of new observations on a NWP forecast (Hoffman and Atlas, 2016; BAMS)
- **Data assimilation at cloud scales is challenging.**
- Fundamentally: OSSEs quantify information in a future observing system
- Consider a spectrum of OSSEs:
  - **Sampling**: What are the sampling requirements for observing a given feature?
  - **Retrieval**: Do measurements provide enough information to estimate geophysical quantities of interest? What are the uncertainties?
  - **Process**: Which measurements are needed to characterize a process (or set of processes)
  - **Forecast**: Does assimilation of new observations improve a weather forecast?

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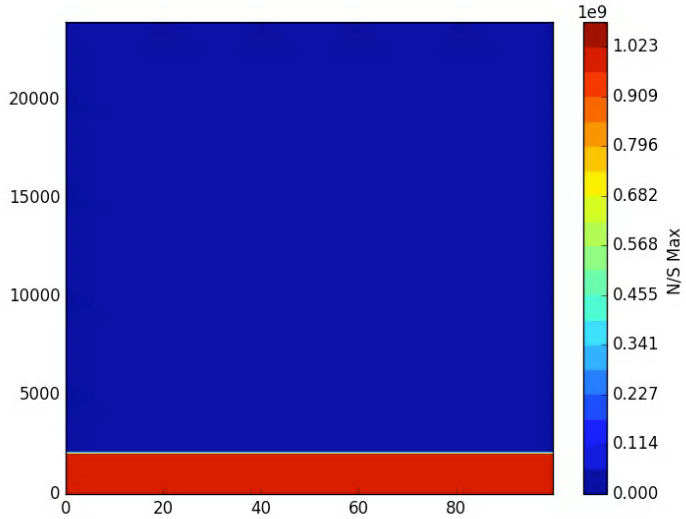
Two (very brief) examples

- Characterize observation uncertainty: retrieval OSSE
  - Active + passive observations of cloud content
  - Explore trade space, quantify uncertainty

$$P(\mathbf{x}|\mathbf{y}) = \frac{P(\mathbf{y}|\mathbf{x})P(\mathbf{x})}{P(\mathbf{y})}$$

- Understand cloud processes: process OSSE
  - Quantify dominant controls on process outcomes
  - Understand model uncertainty



CRM simulation of KWAJEX 11 Aug 1999
250 m dx, 100 km x 100 km domain
Tracer concentration evolution

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Retrievals: Bayesian Perspective

Goal: understand the range of retrieval solutions (uncertainty quantification) and the contribution of various measurements

The solution is a *distribution* of possible outcomes: a PDF

- Can be described using probability theory – what is the likelihood of a particular state, given everything we know about the system of interest?
- Quantify the information we already have (prior, $p(\mathbf{x})$)
- Quantify the influence of new information (observations/likelihood, $p(\mathbf{y}|\mathbf{x})$)
- Quantify the range of solutions, given these pieces of information (analysis/retrieval/posterior, $p(\mathbf{x}|\mathbf{y})$)

$$p(\mathbf{x}\,|\,\mathbf{y}) \mu\ p(\mathbf{y}\,|\,\mathbf{x})p(\mathbf{x})$$

Bayes theorem combines the available pieces of information

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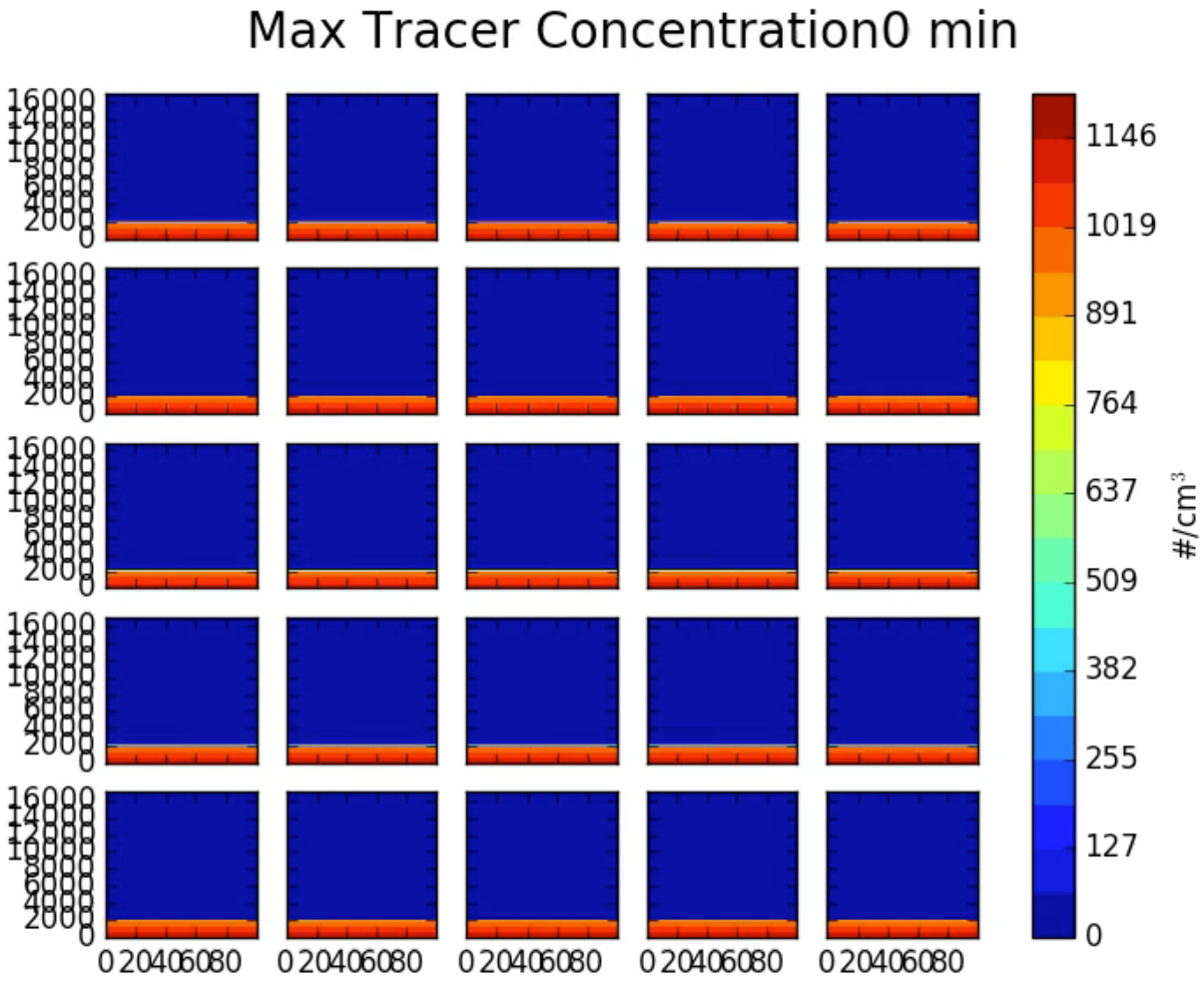
Ensembles to Understand Processes and Model Uncertainty

- Controls: environment and microphysics
- Conduct an ensemble of simulations with perturbed environmental conditions and microphysics
- **Environment sensitivity:**
  - Measurement accuracy
  - Process-level connections
- **Microphysics sensitivity:**
  - Influence of model error on outcomes
  - Effectiveness of obs to constrain model error
- Future: use ensembles to test connection between obs and d/dt



CRM ensemble simulation of TRMM LBA 23 Feb 1999
250 m dx, 100 km x 100 km domain, perturbed soundings

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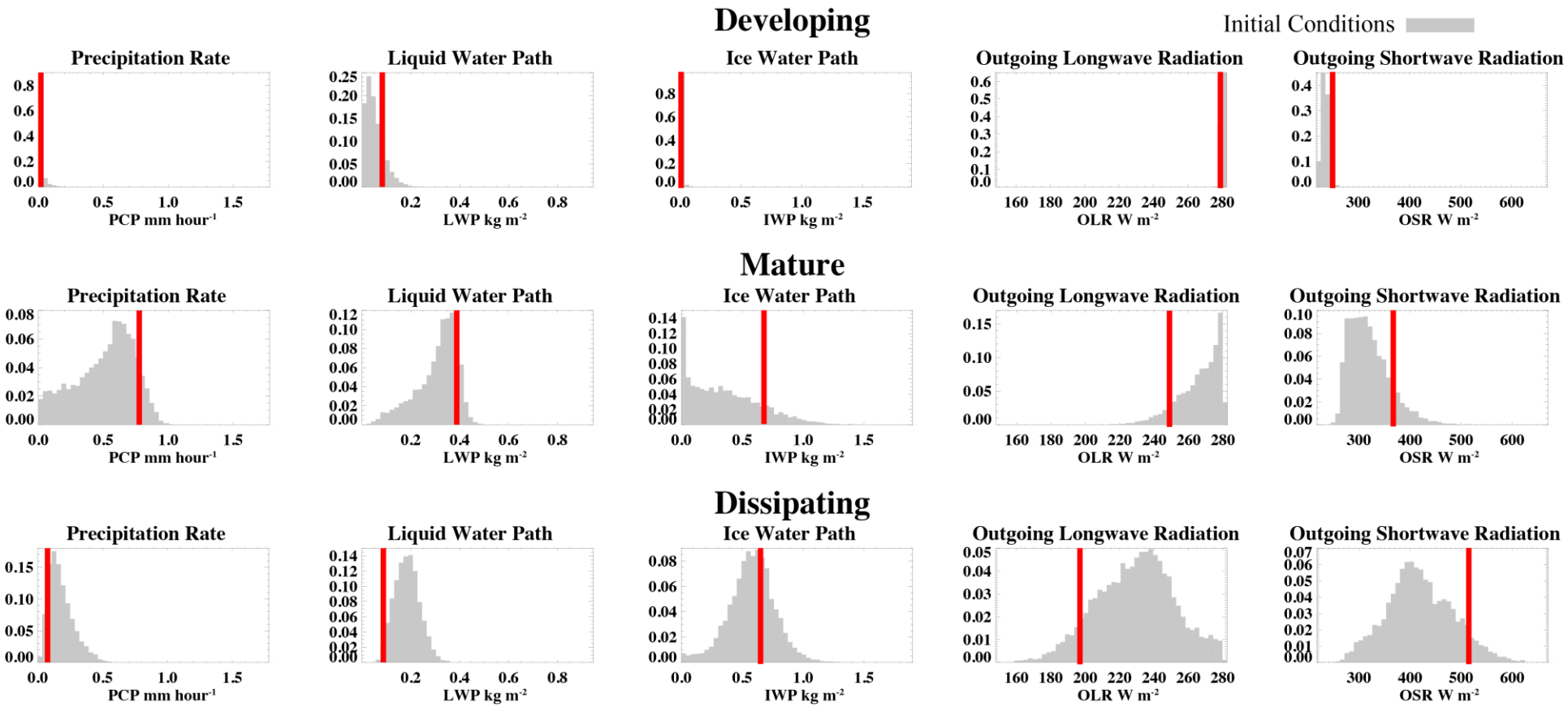
Ensemble Sensitivity Results: Initial Conditions

- Effect on rainfall, cloud content and radiation



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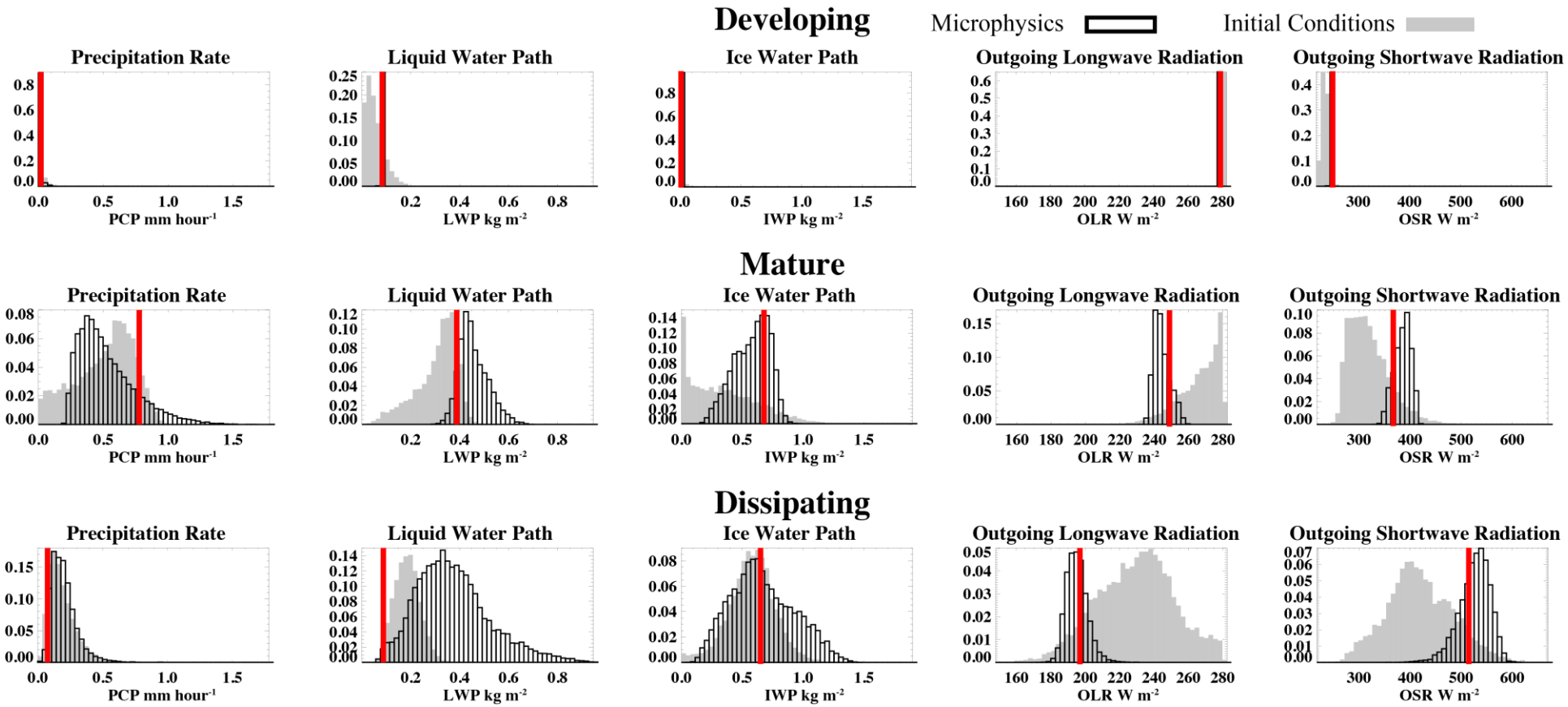
Ensemble Sensitivity Results: Initial Conditions vs. Microphysics

- Effect on rainfall, cloud content and radiation



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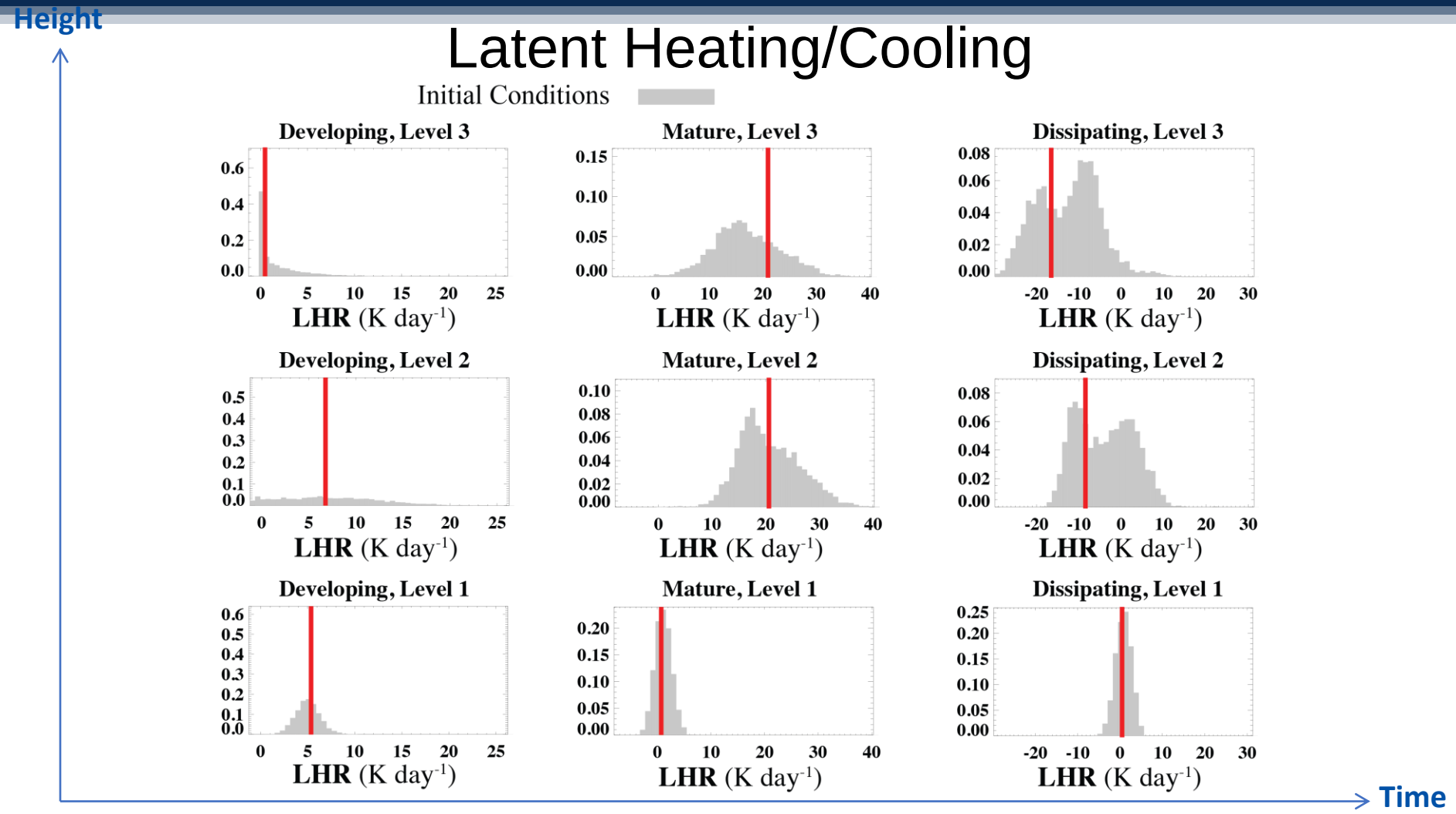
Ensemble Sensitivity Results: Initial Conditions



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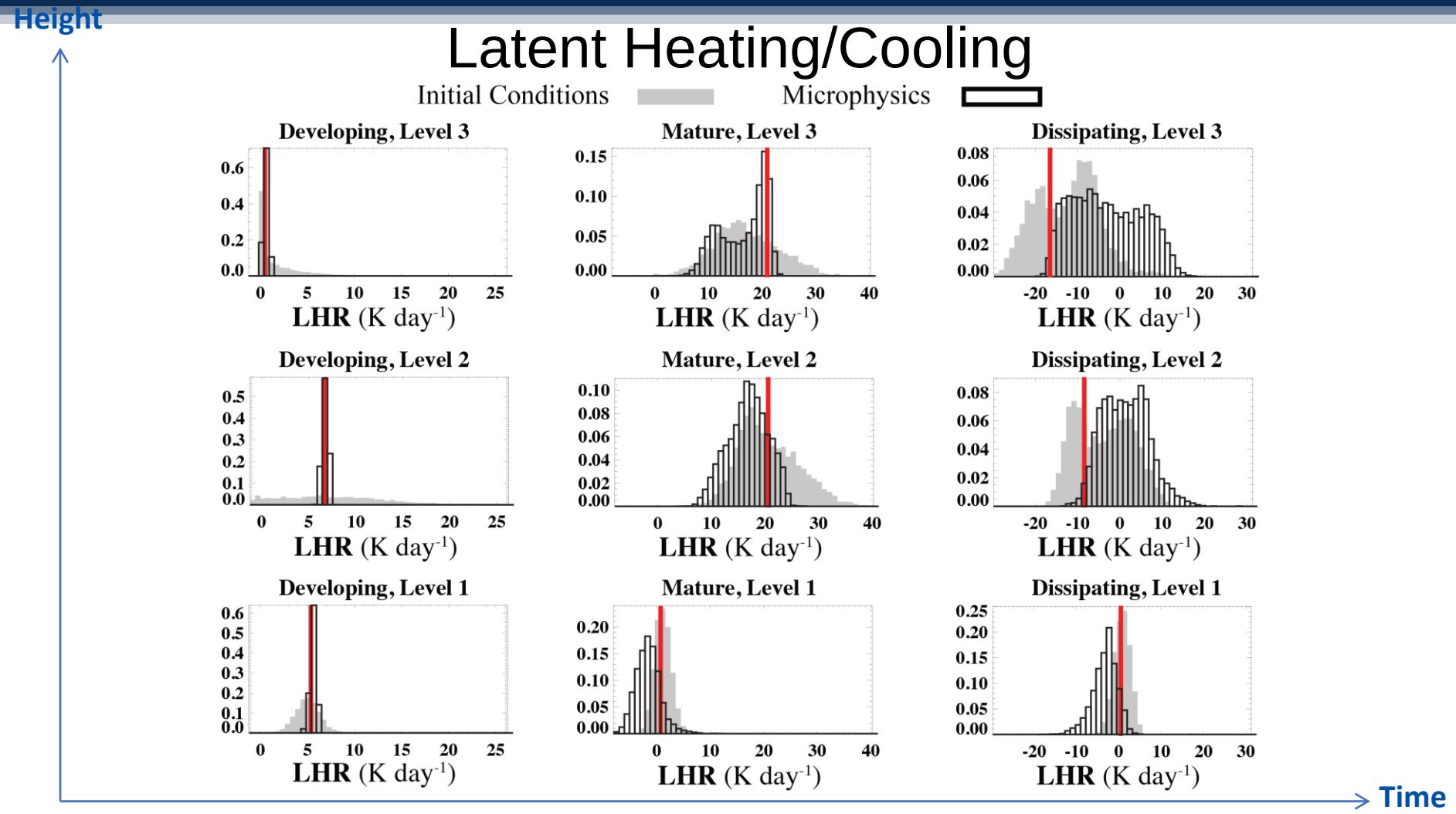
Ensemble Sensitivity Results: Initial Conditions vs. Microphysics



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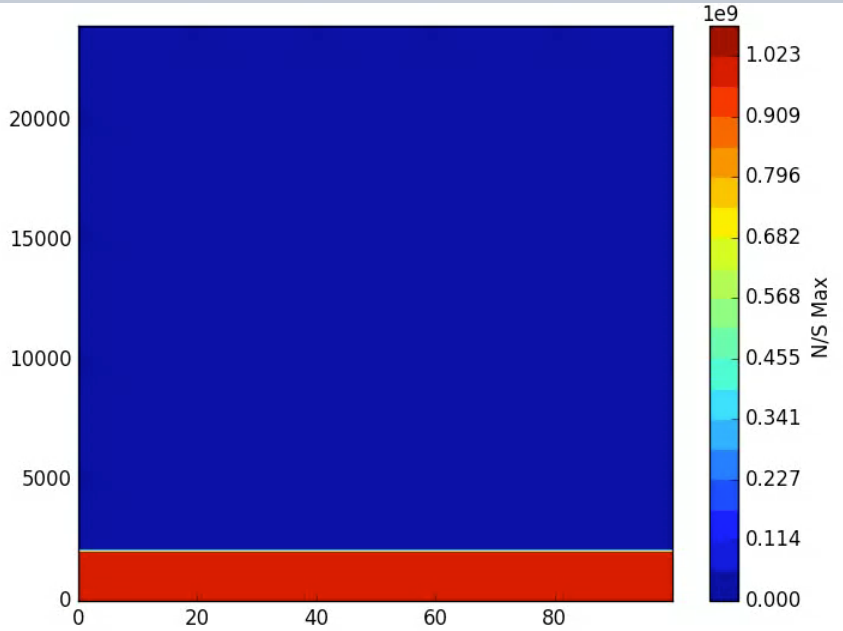
Summary:
Spectrum of OSSEs

- Quantify
  - Measurement accuracy
  - Sampling requirements
  - Process interactions
  - Forecast impact
- Synthetic retrievals can be used to assess information in measurements



- Ensembles of simulations can be used to explore processes, examine model uncertainty, and quantify observing system requirements
- Forecast OSSEs for cloud and convective processes are important, but challenging – require development of cloud-scale data assimilation

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